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INTERNATIONAL PRELIMINARY EXAMINATION REPORT
(PCT Article 36 and Rule 70)

Applicant's or agent's file reference XA 1694	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
International application No. PCT/GB 03/03808	International filing date *(day/month/year)* 03.09.2003	Priority date *(day/month/year)* 14.09.2002
International Patent Classification (IPC) or both national classification and IPC H01Q15/00		
Applicant BAE SYSTEMS PLC et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 6 sheets, including this cover sheet.

   ☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 5 sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the opinion
   - II ☐ Priority
   - III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☐ Lack of unity of invention
   - V ☒ Reasoned statement under Rule 66.2(a)(ii) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
   - VI ☐ Certain documents cited
   - VII ☐ Certain defects in the international application
   - VIII ☐ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
15.03.2004	14.09.2004
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized Officer Kaleve, A Telephone No. +49 89 2399-2249

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/GB 03/03808

I. Basis of the report

1. With regard to the **elements** of the international application *(Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17))*:

Description, Pages

1-3, 5-15	as originally filed
4, 4a	received on 05.08.2004 with letter of 02.08.2004

Claims, Numbers

1-15	received on 05.08.2004 with letter of 02.08.2004

Drawings, Sheets

1/3-3/3	as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

   These elements were available or furnished to this Authority in the following language: , which is:

   ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).

   ☐ the language of publication of the international application (under Rule 48.3(b)).

   ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

   ☐ contained in the international application in written form.

   ☐ filed together with the international application in computer readable form.

   ☐ furnished subsequently to this Authority in written form.

   ☐ furnished subsequently to this Authority in computer readable form.

   ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

   ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

   ☐ the description, pages:

   ☐ the claims, Nos.:

   ☐ the drawings, sheets:

5. ☒ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)).

   (Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

   see separate sheet

6. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	2,4-12,15
	No:	Claims	1,3,13,14
Inventive step (IS)	Yes:	Claims	2,4-12,15
	No:	Claims	1,3,13,14
Industrial applicability (IA)	Yes:	Claims	1-15
	No:	Claims	

2. Citations and explanations

   see separate sheet

Reference is made to the following documents:

D1: US-A-5497168
D2: EP-A-1162687
D3: EP-A-1195847

Re Item I
Basis of the report

1. The amendments filed with the letter dated 02.08.2004 introduce subject-matter which extends beyond the content of the application as filed, contrary to Article 34(2)(b) PCT. The amendments concerned are the following:

1.1 Claim 1:

Addition of 'comprising period spatial variations on a scale that is much smaller than the wavelength of incident radiation'

According to grammar rules the added part refers to 'conducting LC elements'. However, LC elements comprising period spatial variations on a scale that is much smaller than the wavelength of incident radiation have not been disclosed in the application as filed. The sole relevant part disclosed in the application as filed pertains sentence on page 1, lines 8-11, which, however, is about the structure and not its elements.

Further examination of claim 1 and its dependent claims has been established as if said addition had not been made.

Besides, it is to be noted that even if the applicant added the original wording of page 1, lines 8-11 into claim 1, this part would not be regarded as being limiting for the scope of the claim, since the expression of 'periodic spatial variations in a structure' appears to be highly vague and unclear.

1.2 Claim 2 and page 4 last paragraph to page 4a:

Addition of the expression 'metamaterial' in claim 2, and its definition in the description

Neither the expression 'metamaterial' nor its definition has been disclosed in the application as filed. Therefore, examination has been established as if in claim 2 and on page 4a, line 7 'metamaterial' had been replaced by 'material' and the paragraph starting on page 4 had been deleted.

Re Item V

Reasoned statement under Rule 66.2(a)(ii) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. The subject-matter of claim 1 does not meet the requirements of Article 33 PCT with respect to novelty, since D2 discloses an antenna array being a periodic electromagnetic structure comprising all features set out in claim 1:
- an array of conducting LC-elements (see figure 6: the resonating patches can be seen as LC elements);
- the array being superimposed with a frequency-dependent dielectric whose permittivity varies according to the frequency of radiation incident thereon such that the resonant frequency of the LC elements follows the frequency of the incident radiation (see page 4, par. 24 and figure 5).

The additional features of dependent claims 3, 13 and 14 are disclosed in D2 as well.

2. In addition, D1 (see abstract and figure 9) is novelty destroying for the subject-matter of claims 1, 3 and 13.

3. The subject-matter of claim 2 fulfills the requirements set out in Article 33 PCT, since the difference with respect to the closest prior art D3 being that the array is superimposed with a frequency-dependent dielectric whose permittivity varies according to the frequency of radiation incident thereon such that the resonant frequency of the LC elements follows the frequency of the incident radiation, is not rendered obvious by the prior art on hand. In fact, none of the documents cited in the search report discloses or suggests to combine materials as defined in claim 2 with frequency dependent dielectrics.

4. Dependent claims 4-12 and 15 fulfill the requirements set out in Article 33 PCT, for substantially the same reasons as set out with respect to claim 2.

5. It seems to be essential for the definition of the claims (Article 6 PCT) that the claims relating to figures 1-9 refer to 'high-impedance surfaces', the claims relating to figures 10 and 11 refer to 'negative refractive index materials' and the claims relating to figures 12 and 13 refer to 'chiral materials'. However, independent claim 1 does not contain said features.

6. Although claims 1 have been drafted as separate independent claims, they appear to relate effectively to the same subject-matter and to differ from each other only with regard to the definition of the subject-matter for which protection is sought and in respect of the terminology used for the features of that subject-matter. The aforementioned claims therefore lack conciseness and as such do not meet the requirements of Article 6 PCT.

7. According to page 14, lines 25 to 27 the helical elements 68 may be made from a dielectric material, a ceramic or a plastic. Contrary to that, independent claims 1 and 2 expressively states that said LC elements are conducting. This contradiction between the claims and the description leads to doubts as to the matter for which protection is sought and thus, violates Article 6 PCT.

impedance surfaces, high reflectivity and in-phase image currents only occur over a narrow resonant frequency range. For split-ring resonators, the structure only displays the desirable combination of negative permeability and negative permittivity over a narrow range of resonant frequencies. For chiral structures, they impart the microwave properties only over their narrow range of resonant frequencies. In each case, the resonant frequency is determined by the well known equation

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

where the inductance (L) and capacitance (C) of the LC elements are, in turn, determined by the geometry of the structure. Accordingly, the structures are of limited use due to their narrow operating bandwidth, typically a few tens of percent.

One technique that has been implemented to increase their operating bandwidth is to include non-linear voltage-dependent components in the structure, such as varactor diodes. The use of varactor diodes allows the operating frequency of a high-impedance surface to be changed by changing the bias voltage across the varactor diode. This allows the resonant frequency of the LC elements to be changed by a factor of two. However a significant problem with the use of varactor diodes is that the two dimensional array of LC elements require a complex network of conductors to supply the bias voltage to each diode.

Hence, there remains a general need for periodic electromagnetic structures that display their advantageous properties over a wider range of frequencies. For example, one requirement is for multifunction antennas that will allow a wide range of frequencies to be transmitted by a single antenna structure, thereby reducing the number of separate antennas that are required on a single platform.

For the purposes of this specification, the above exemplified periodic electromagnetic structures may alternatively be referred to as "metamaterials". Thus, for the purposes of this specification, a metamaterial is a periodic

electromagnetic structure comprising an array of conducting LC elements that cooperate together to provide a material that is one of the group of High Impedance Surfaces, Ultra-Compact Photonic Band Gap devices, negative-refractive index materials, and chiral materials.

The present invention resides in one aspect in a periodic electromagnetic structure comprising an array of conducting LC elements that co-operate together to provide a metamaterial in superposition with a frequency-dependent dielectric whose permittivity and/or permeability varies

CLAIMS

1. A periodic electromagnetic structure (20) comprising an array of conducting LC elements (22;22a,22b;42;52;68) comprising period spatial variations on a scale that is much smaller than the wavelength of incident radiation, said array being superimposed with a frequency-dependent dielectric (30;44;54;70) whose permittivity and/or permeability varies according to the frequency of radiation incident thereon such that the resonant frequency of the LC elements follows the frequency of the incident radiation.

2. A periodic electromagnetic structure (20) comprising an array of conducting LC elements (22;22a,22b;42;52;68) that co-operate together to provide a metamaterial that is one of the group of High Impedance Sufaces, Ultra-Compact Photonic Band Gap devices, negative-refractive index materials and chiral materials, said array being superimposed with a frequency-dependent dielectric (30;44;54;70) whose permittivity and/or permeability varies according to the frequency of radiation incident thereon such that the resonant frequency of the LC elements follows the frequency of the incident radiation.

3. The structure of claim 1 or 2, wherein the frequency-dependent dielectric has a response to incident radiation such that the product of the permittivity and permeability of the dielectric varies in proportion to the reciprocal of the square of the frequency of the incident radiation.

4. The structure of claims 1, 2 or 3, that is a High Impedance Surface, wherein each LC element is a protrusion (22;22a,22b) from a flat conducting plate (24).

5. The structure of claim 4, wherein the frequency-dependent dielectric abuts the conducting plate and the protrusions extend at least partially into the dielectric.

6. The structure of claim 5, wherein the protrusions are generally thumb tack shaped.

7. The structure of claim 3, that is a High Impedance Surface, wherein the structure forms an ultra compact photonic bandgap device (40), said LC elements being formed from a patterned conductive sheet, mounted on a grounded dielectric substrate.

8. The structure of claim 3, that is a negative-refractive index material, wherein each LC element comprises a split ring resonator (50).

9. The structure of claim 7 or claim 8, wherein the LC elements are disposed across the surface (43;53) of the frequency-dependent dielectric.

10. The structure of claim 3, wherein each LC element comprises a chiral conductor (68).

11. The structure of claim 10, wherein each chiral conductor is helical in form.

12. The structure of claim 10 or claim 11, wherein the chiral conductors are set within the frequency dependent dielectric (70).

13. An antenna comprising a periodic electromagnetic structure according to any preceding claim.

14. A mobile phone handset comprising an antenna according to claim 13.

15. A radar absorbent material comprising a periodic electromagnetic structure according to any of claims 1 to 12, wherein the impedance of the structure is substantially 377 Ω, thereby to match the impedance of free space.